



# Auroral Science Facts and Myths

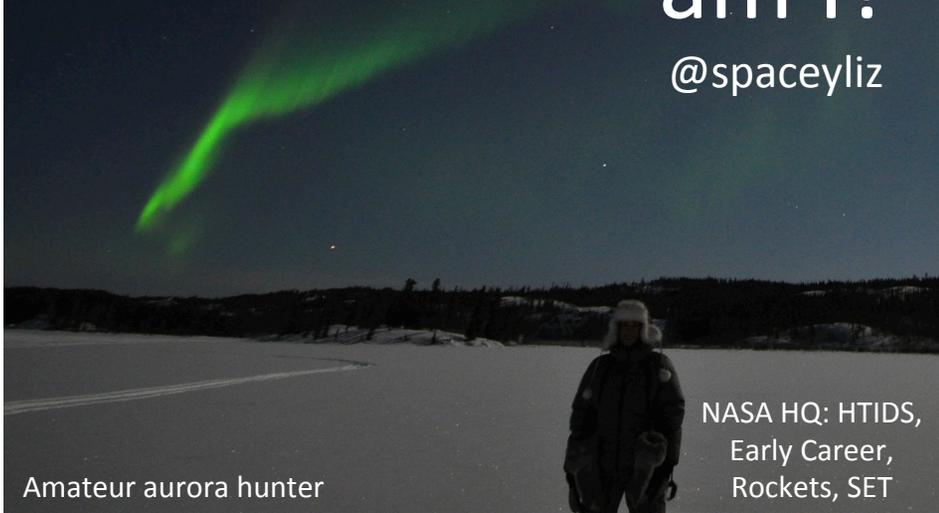
Dr. Liz MacDonald, NASA, @spaceyliz  
founder, Aurorasaurus.org @tweetaurora

Largely qualitative low jargon introduction

## Homework

- Interactive learning module, good graphics of physics, get free account
  - Physics of the aurora: <http://www.meted.ucar.edu/hao/aurora/>
  - Space Weather basics: <http://www.meted.ucar.edu/spaceweather/basic/>
- Book: Storms from the Sun: free download
  - <https://www.nap.edu/catalog/10249/storms-from-the-sun-the-emerging-science-of-space-weather>

# Who am I? @spaceyliz



Amateur aurora hunter

Co-I on HOPE, H+, He+, O+, e-

NASA HQ: HTIDS,  
Early Career,  
Rockets, SET

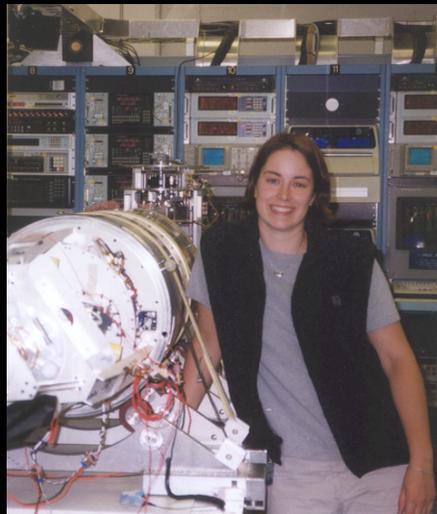
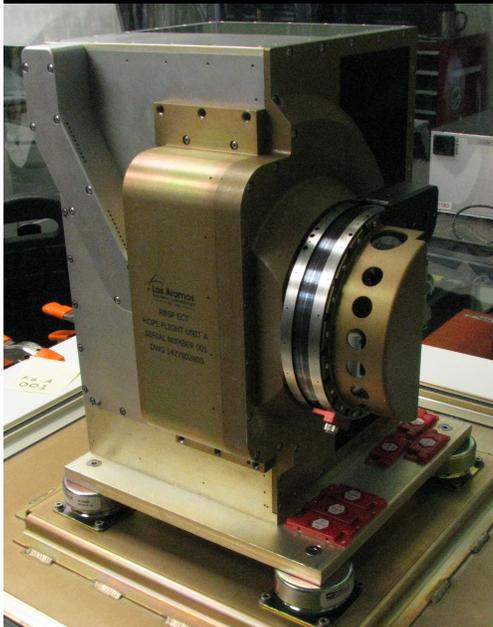


Rocket scientist in pursuit  
of thermal electrons

Los Alamos National Lab projects:  
Van Allen Probes,  
geosynchronous orbit plasma,  
and instrument calibration

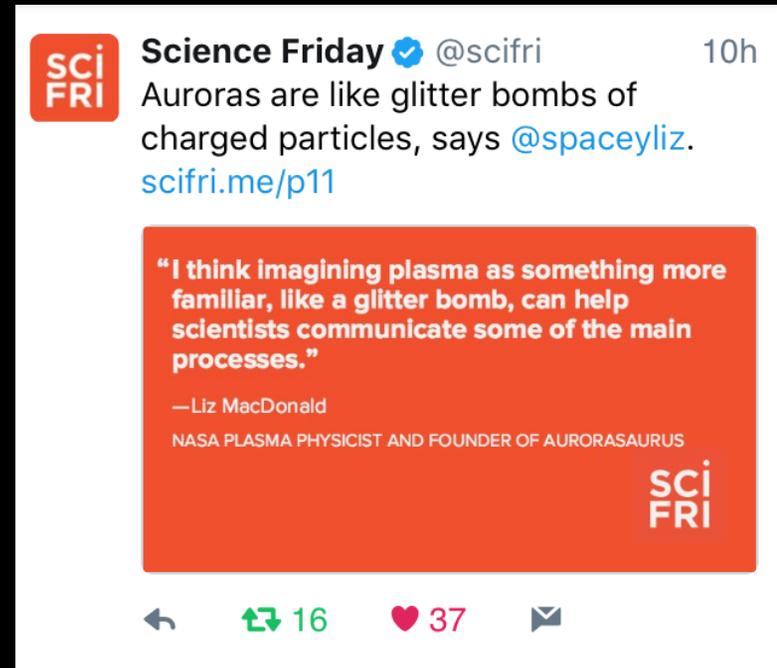


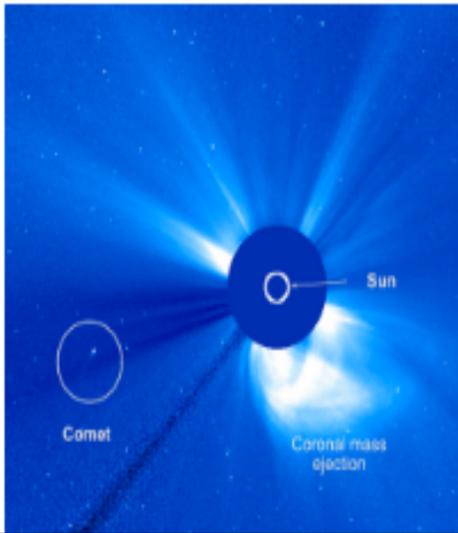
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# Outline

- Take notes. Blogging opportunity.  
*blog.aurorasaurus.org*
- 6 myths about aurora
- Ways to study aurora: citizen science, rockets, satellites, models

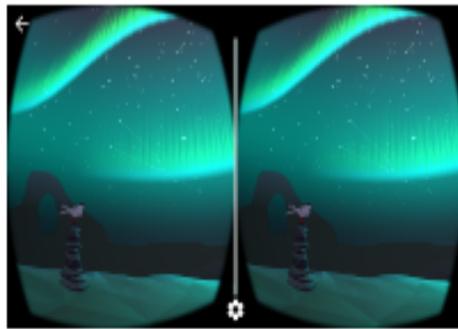




## Space Weather at our Doorstep: How Can We Detect it?

Posted on *July 29, 2016*

Identifying Space Weather Phenomena Space weather is a complex field of study and can be a difficult term to define. According to NOAA's Space Weather Prediction Center (SWPC), space weather is described as the variations in the space environment between the sun and Earth. Other planets have space weather, too. In fact, we have been[...]



## Check out Virtual Reality Aurora!

Posted on *November 1, 2016*

Aurora only occur in particular areas of the world and are highly unpredictable which are some of the reasons why many people feel fortunate to see them at all. And, for the majority of known human history, you could only experience the beauty and mystique

## Aurorasaurus Tracks St. Patrick's Day storm on Social Media

Posted on *March 19, 2015*

By Nathan Case and Kasha Patel An Aurorasaurus user submitted this photo of the aurora in Germany along with a report. On Tuesday, March 17, 2015, as people adorned themselves with green clothing and infused their livers with green beer, Earth was experiencing the biggest geomagnetic storm of the last decade—leading to beautiful,



# How is aurora formed?

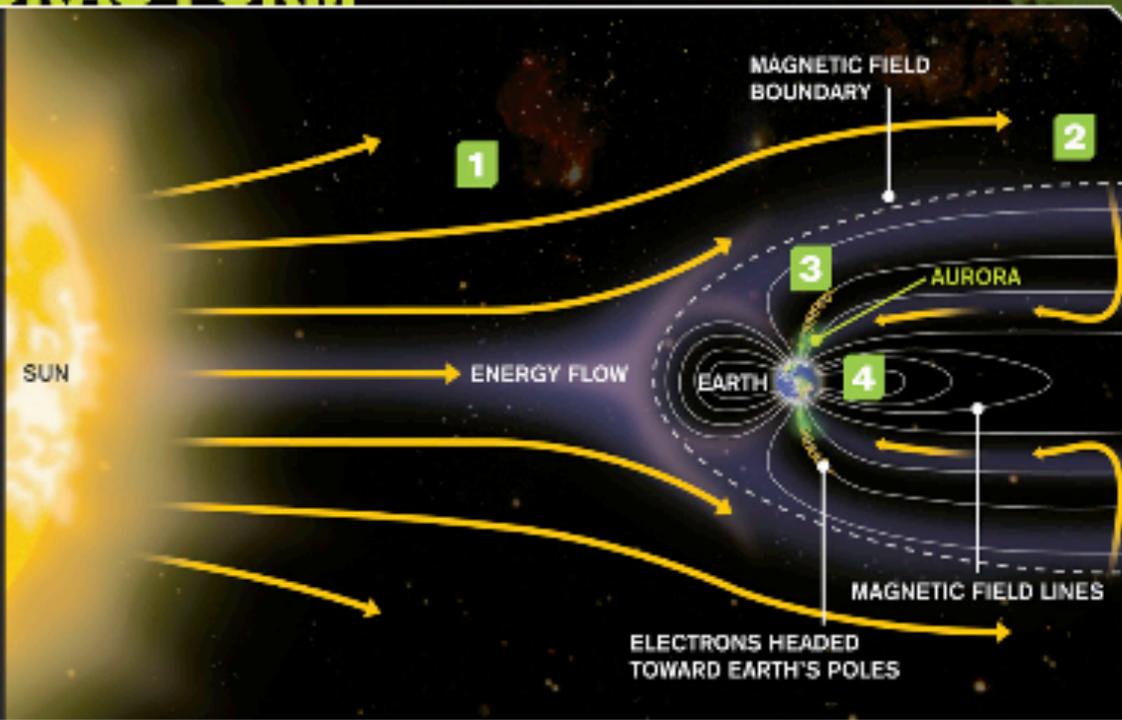


# Myth No. 1 – how aurora forms

**DAZZLING DISPLAYS:** An aurora filled the sky above Iceland for about an hour last March.

## HOW AURORAS FORM

- 1** Energy particles flow from the sun toward Earth.
- 2** Earth's magnetic field usually deflects most of the charged particles. It traps the rest.
- 3** Trapped particles collide with Earth's magnetic field. This causes electrons to race down Earth's magnetic field lines toward the poles.
- 4** The night sky near the poles lights up with auroras when electrons strike oxygen and nitrogen gas in Earth's upper atmosphere.



# Myth No. 1

## Aurora is formed by particles from the sun

### AURORA BOREALIS EXPLAINED

**1** The sun showers the Earth with electrically charged particles that collide with the upper reaches of Earth's atmosphere.

**2** Earth's magnetic field leads those particles towards two aurora ovals centered at the magnetic poles.

**Aurora Borealis**  
(Northern Lights)



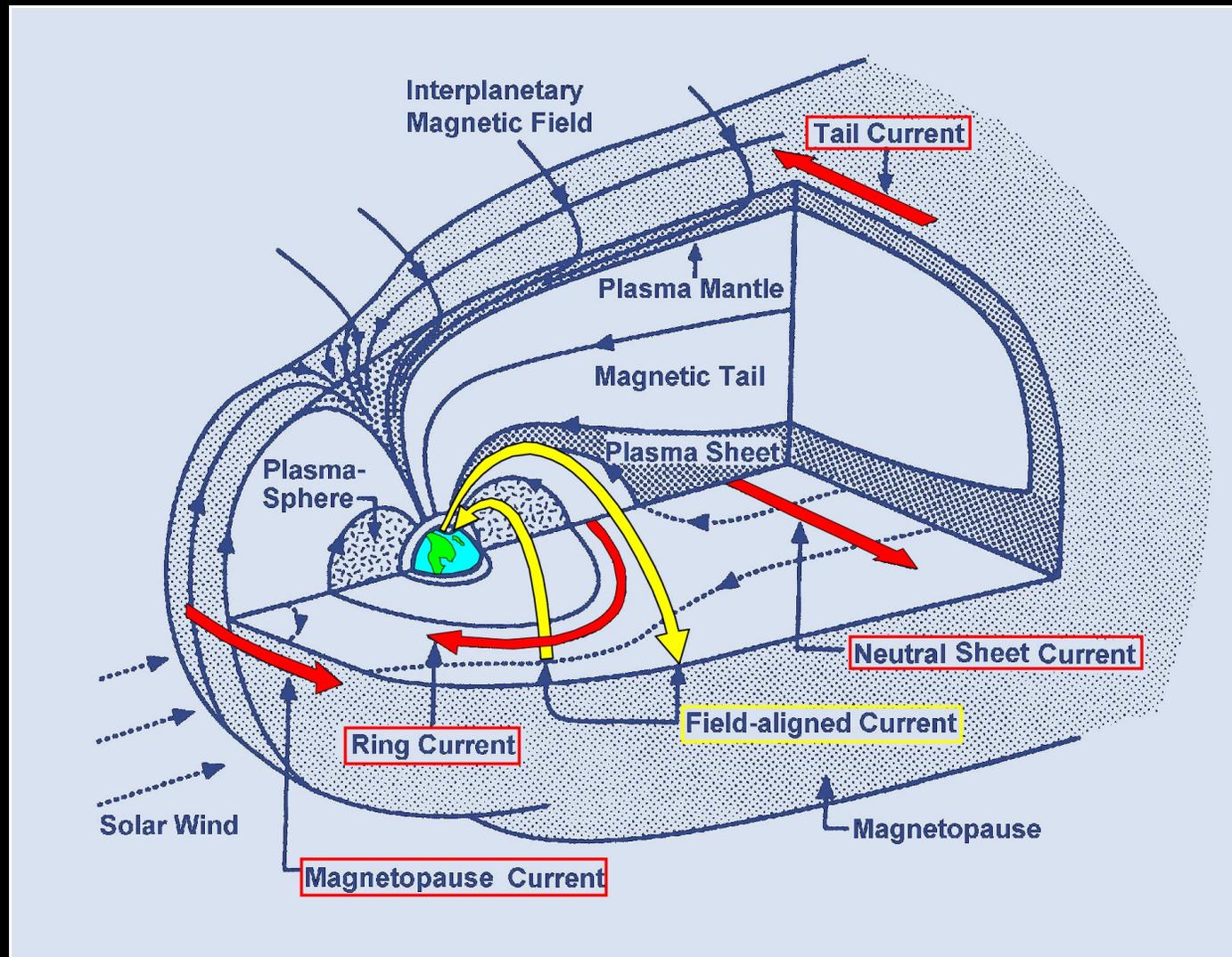
**Aurora Australis**  
(Southern Lights)

**3** The particles collide with oxygen and nitrogen atoms and molecules in Earth's upper atmosphere, releasing energy in the form of different colors of light.

**NO!!!**

SUN

# Meet the magnetosphere!



## Kinesthetic learning to show magnetohydrodynamic convection

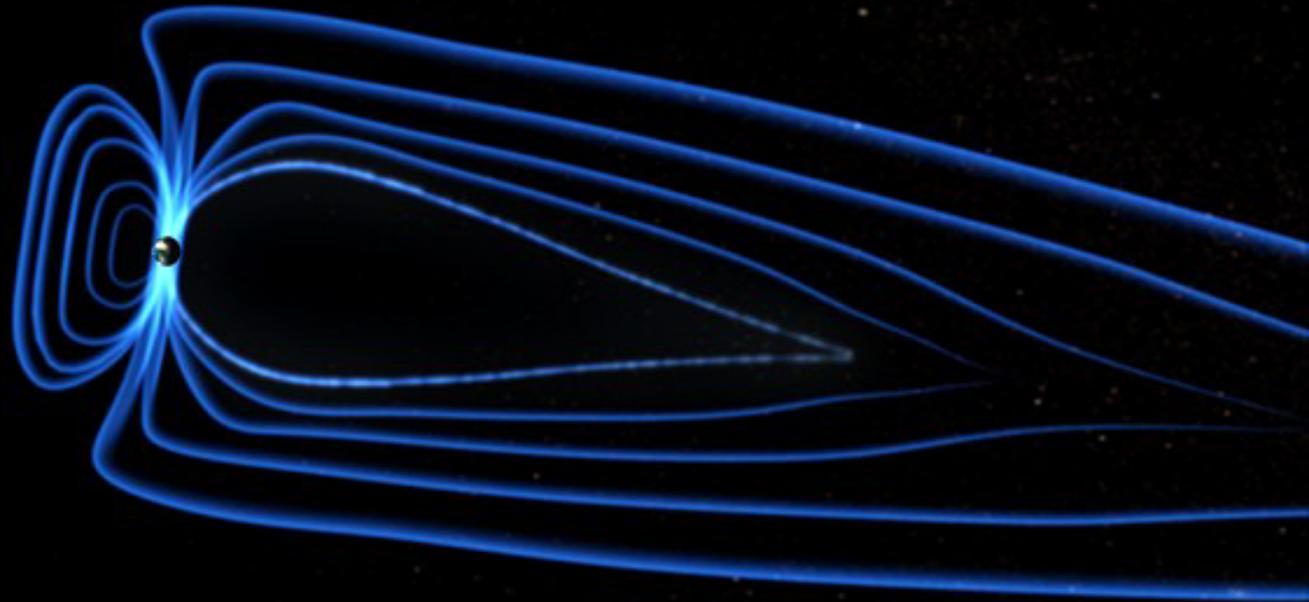
- The magnetosphere is an obstacle in the flowing solar wind. Therefore magnetospheric convection (in the equatorial plane) is somewhat like doing the breaststroke in an endless pool. Plus the dipole field out of the plane = magnetohydrodynamics
- <https://youtu.be/i4mKvlulGDg>

## Myth 2, when does aurora happen?

- All the time!
- Symmetric to both hemispheres
- Even during daylight

# Myth No. 2

## Aurora happens during storms



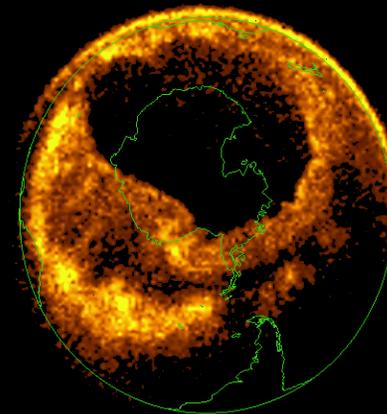
# Lack of accurate imaging perpetuates myth

## Why?

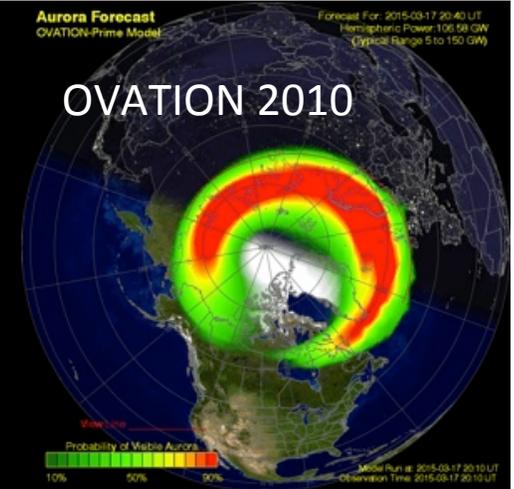
- Science gaps
  - The evolution of aurora during large storms never fully imaged or characterized
  - Aurora is fine scale but models are coarse
  - Aurora are tracers of fundamental, global coupling processes and connections are very sparse
- Communication gaps
  - Inspiring source of engagement
  - Not digestible by the public

## Goals

- Better nowcasts and awareness
- First data assimilative model of auroral visibility



DE-1, during 1989 superstorm  
89 073 0151 UT



Space Weather:  
Highly dynamic poorly characterized threats  
Scintillations, GIC, spacecraft charging

# “Everyday aurora” Phenomenology of Auroral Substorm

Akasofu picture of the aurora during  
substorms:

- (a) Quiet auroral arc before substorm
- (b) Equatorward edge of aurora intensifies
- (c) “Westward traveling surge” forms
- (d) Poleward expansion of surge
- (e) Aurora begins to fade; patchy  
“pulsating aurora” forms on dawn
- (f) Auroral oval retreats to pre-substorm  
locations

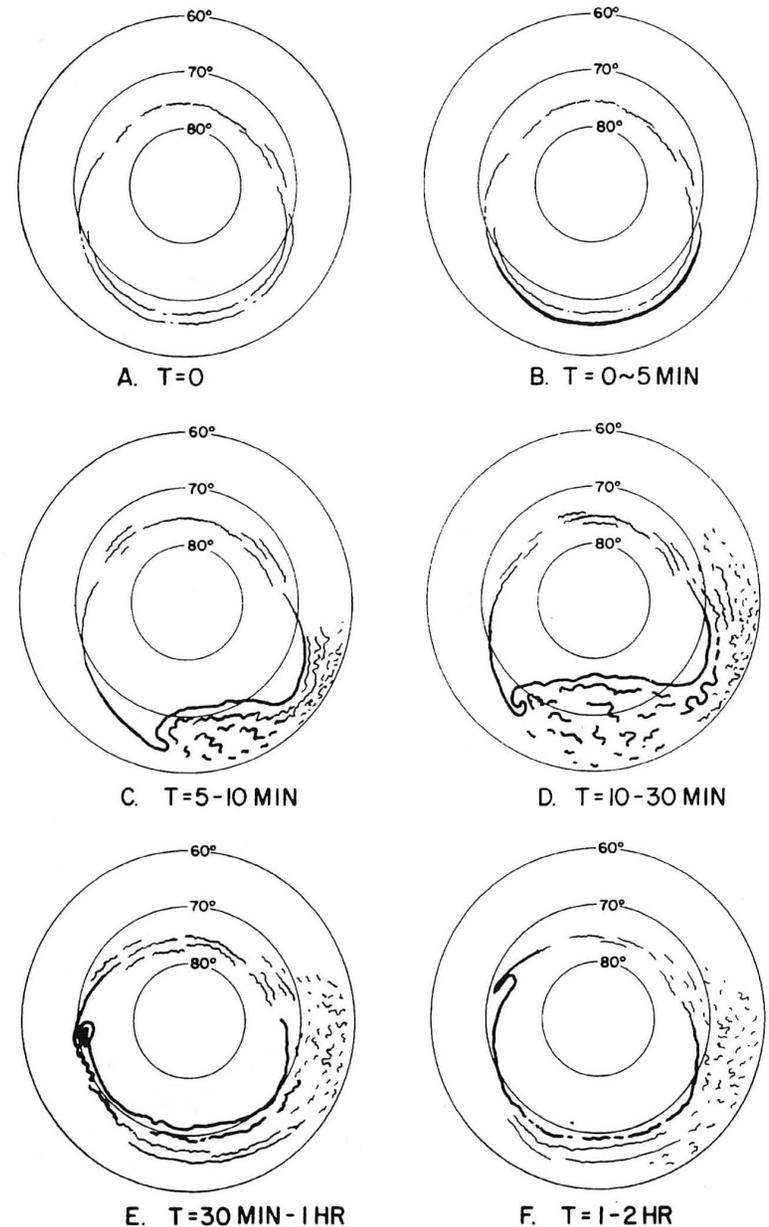


Figure 8. The schematic illustration to show how the auroral substorm develops and subsides.

# Myth No. 3

## Aurora is understood.



**Athabasca, AB, Canada**  
**2003/07/27 05:12:00 UT**

# SPACE WEATHER

EXPLORING SUN-EARTH CONNECTIONS

SOLAR FLARE





# What causes the Aurora?

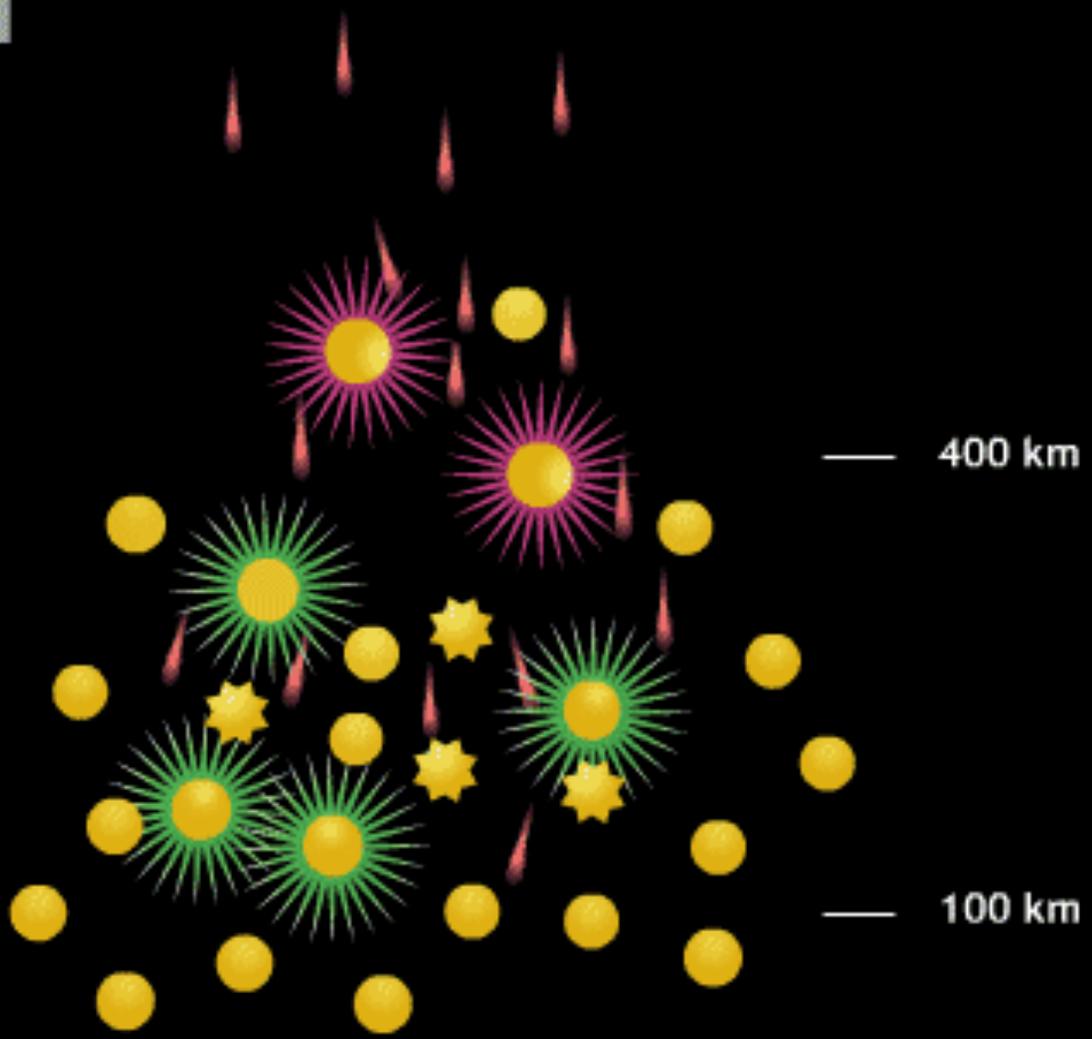
electrons hit  
air molecules



molecules  
are "excited"

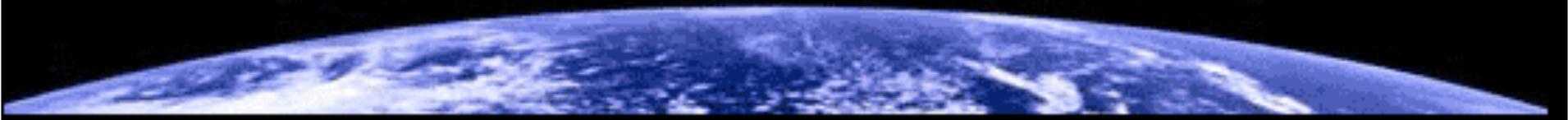


molecules  
give off light as  
they calm down



400 km

100 km



# Infographics on color

<http://blog.aurorasaurus.org/?cat=8>

## WHY is green the most common color for an aurora?



Aurora can appear in many colors, but green is the most common. You may have seen an eerie green glow in the sky or in a science fiction movie.

SciFi has it right and here's why!

The green light comes from excited oxygen atoms...



While nitrogen is the most common element in our atmosphere, oxygen is the most common element at the altitude where aurora occur (100 - 500 km).



You may recall that excited oxygen atoms can emit red or green light, depending on how much extra energy they have. So, why aren't red aurora more common?

It's all about timing and collisions.

When two atoms collide, energy is transferred between them.



If an oxygen atom is excited to the energy level corresponding to green...

... and it has no collisions...

... then it will emit light after 1 second.

If an oxygen atom is excited to the energy level corresponding to red...

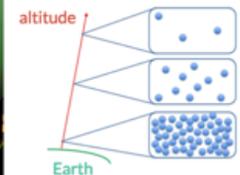
... and it has no collisions...

... then it will emit light after 110 seconds.



It may seem short to you, but 110 seconds is a long time for an excited oxygen atom to avoid collisions!

Because it takes so long, red light is only emitted in the higher regions of the atmosphere (above 200 km) where atoms and molecules rarely collide.

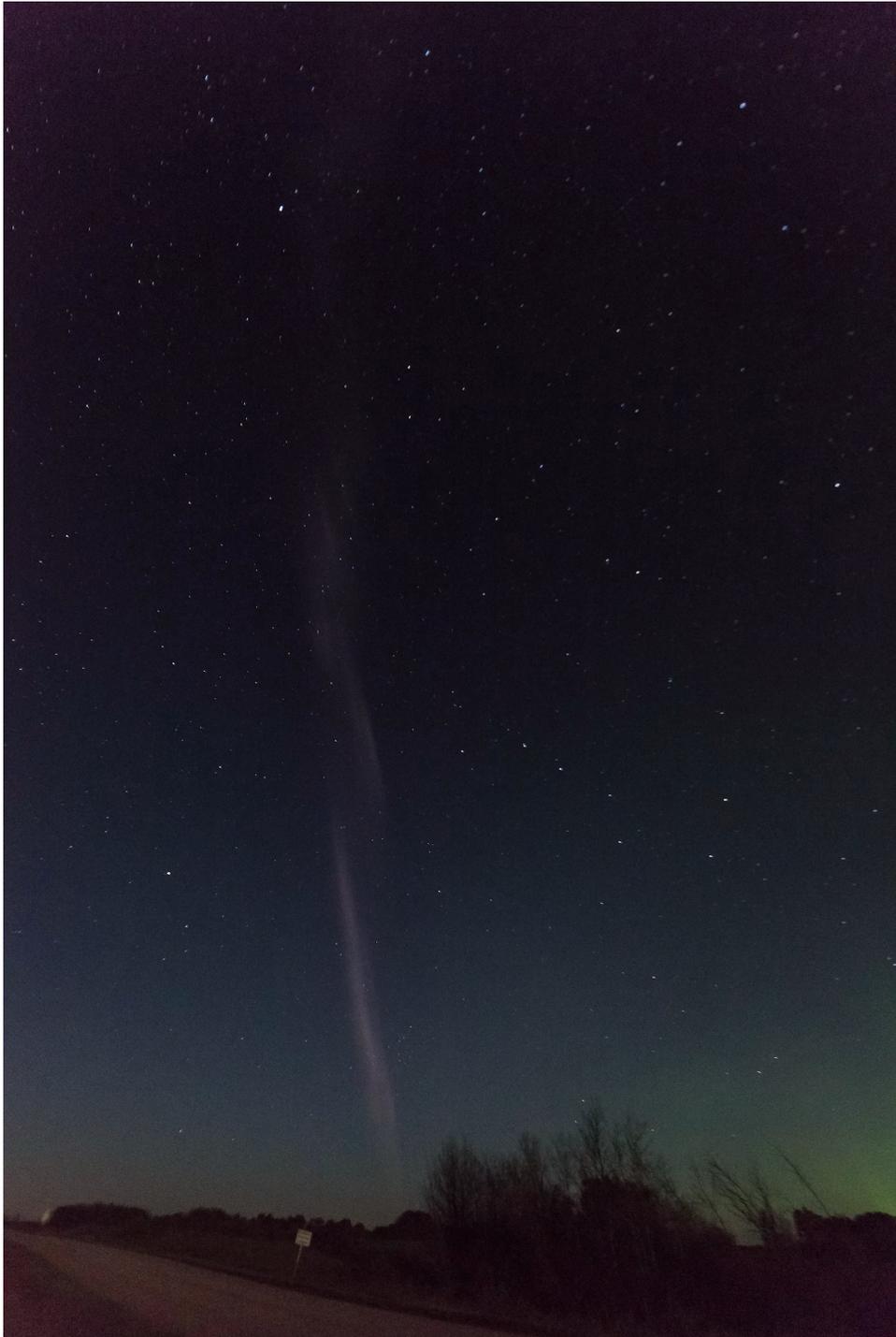


Blue, pink, and violet may also appear, especially near the lower boundary of aurora, due to higher levels of nitrogen below 100 km. But these colors are much less common than green.



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v032715



## What don't we know?

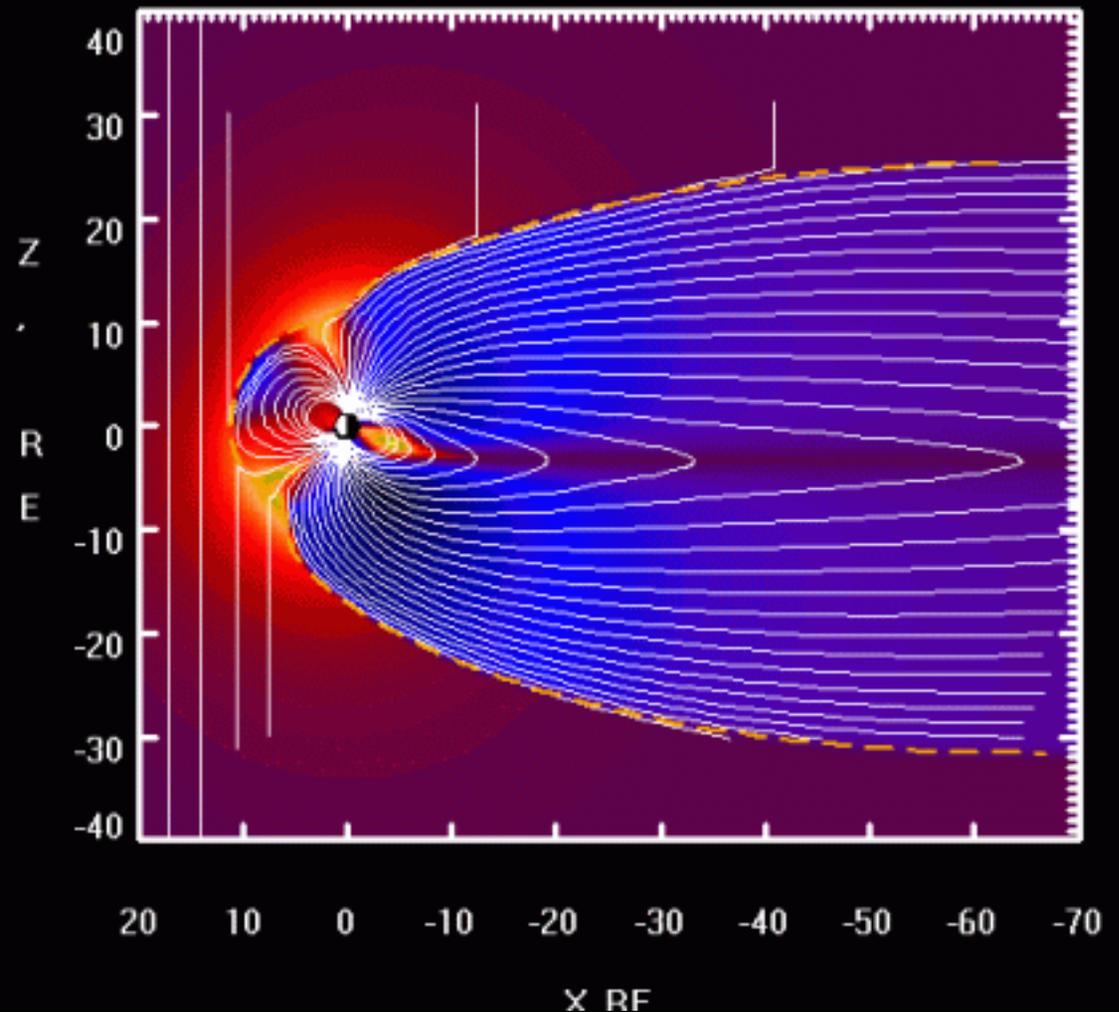
- Timelapse photos with color DSLR at lower than usual latitudes
  - Different viewpoint
- “Proton arc” that is not a proton arc → STEVE
- Traditional science may be missing something
  - Complementary to citizen science observations, filtered by wavelength, precise time, timelapse, fisheye view

Credit: Notanee Bourassa,  
Alberta Aurora Chasers

# Myth No. 4

## Magnetic field lines are static.

- <http://geo.phys.spbu.ru/~tsyganenko/modeling.html>
- Average statistical picture
- Don't apply to substorms



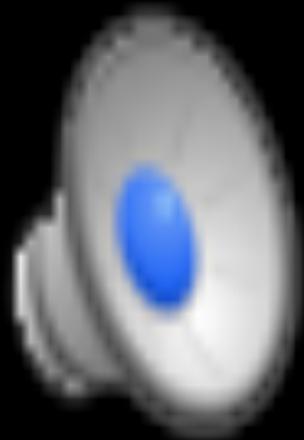


# Myth No. 5

## Aurora is static.

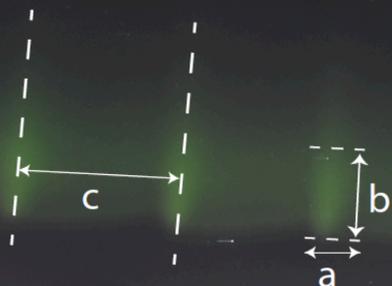
- Need to observe to appreciate
- Hard to measure all scales – data starved

<http://blog.aurorasaurus.org/?p=414>



## Citizen Science Image of Unusual Auroral Beads

Ray Width (a) ~ 5 km  
Ray Length (b) ~ 15 km  
Bead Separation (c) ~ 20 km  
Total Arc Size ~ 500 km  
Dst = -128 nT

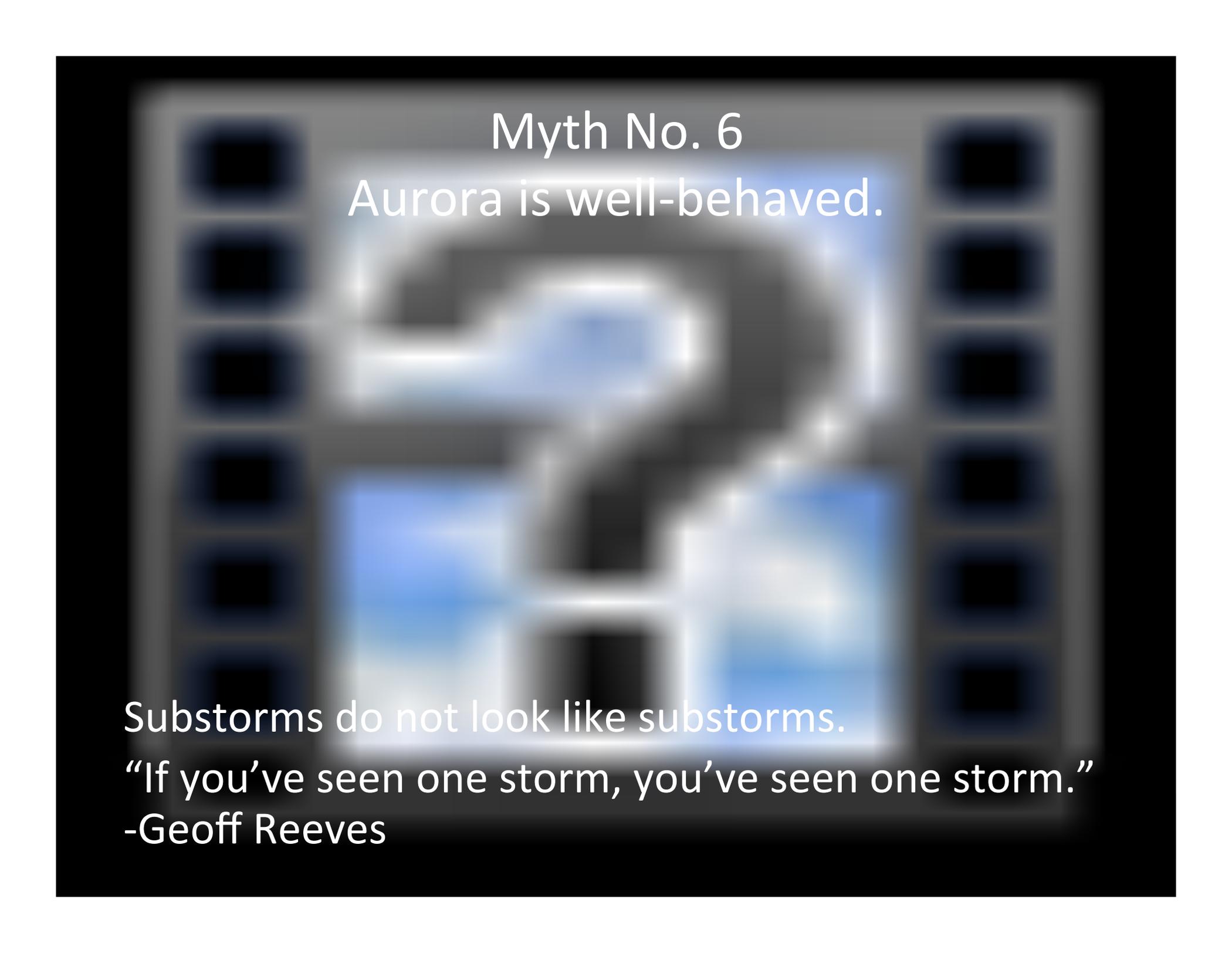


2015:12:21 05:01:58 UT

Taken from Saskatoon  
Moon was in the sky  
Esposure time: 2.5s  
Lasted ~ 4 minutes

52° 5' 10" N, 106° 26' 2" W  
2015:12:21 05:01:58 UT

Image credit Alan Duffy

The background of the slide is a dark, blurred image of a grid of satellite images. The grid consists of approximately 10 columns and 10 rows of small, square panels. Each panel appears to show a different view of the Earth's aurora, with varying intensities and patterns of light. The overall effect is a sense of a large-scale, multi-point observation system.

Myth No. 6  
Aurora is well-behaved.

Substorms do not look like substorms.

“If you’ve seen one storm, you’ve seen one storm.”

-Geoff Reeves

# To recap 6 myths...

1. Particles straight from the Sun cause the aurora.
  - Nope magnetosphere plays a big role.
2. Aurora only occurs during solar storms.
  - Nope, aurora occurs all the time.
3. Aurora is understood. No. Many basic things are understood, many are not.
  - No global imaging. Gaps in our knowledge. Lack of realistic models
4. The magnetic field is static.
  - No, highly highly stretched and dynamic.
5. Aurora is static.
  - No. Dynamic and MULTI-scale.
6. Aurora is well-behaved.
  - In actuality, if you've seen one storm, you've seen one storm

Enter citizen science and Aurorasaurus, other ways to study aurora. Satellites, rockets, models. Model are tools, ask about about the uncertainties. Understand the limits and assumptions. The largest storms exhale tons of oxygen. Where is the oxygen?

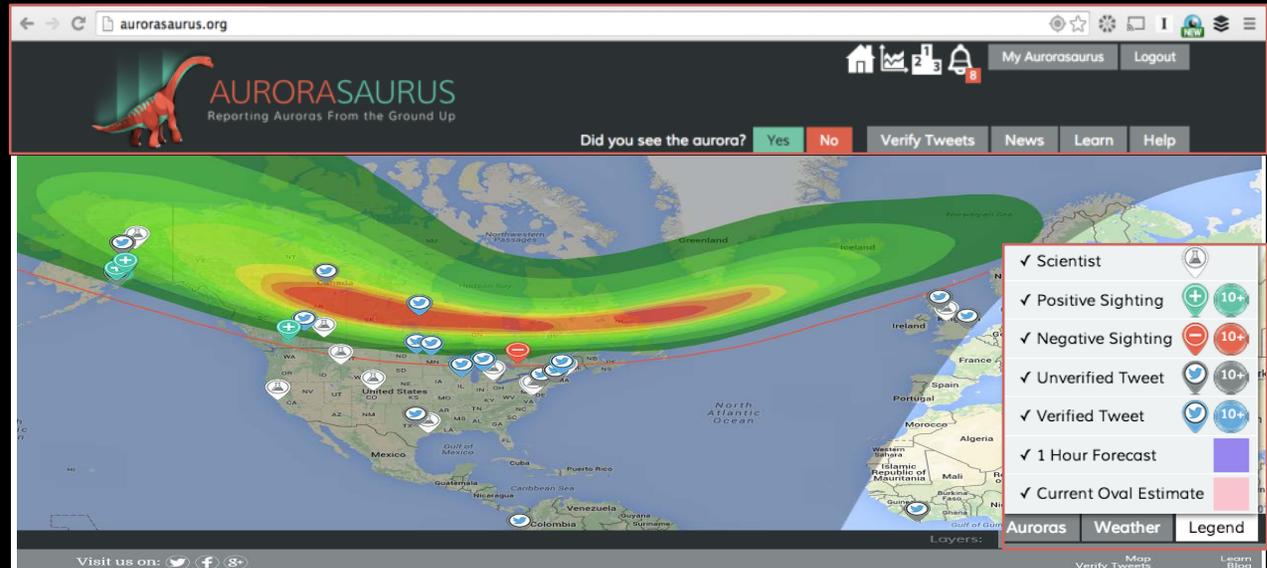
# What is Aurorasaurus?

THE 'AURORASAURUS' MAPS THIS YEAR'S  
SPECTACULAR AURORAS

WIRED

- New... global
  - Idea in 2011, full launch in 2014, not possible during last solar max
  - 51% users from US, “aurora enthusiasts”
- Fast... but unpredictable
  - Real-time alerts
  - Multiscale accuracy is a challenge
- Obscure... but beautiful
  - Historical examples of aurora cit sci and crowdsourcing
  - Communication challenges
- Evolving, expanding, continual process
  - Open innovation, open source, extensible, agile, disruptive
  - Part of a new tech-driven citizen science movement
  - Citizen science projects can monitor weather, disasters, and rare biological phenomena accurately in real-time.
    - <http://citizenscience.gov/>

Aurorasaurus.org  
Apple iOS & Android apps



## New global, real-time data sources from citizen scientists and tweets Alerts of auroral visibility for the public

In 2 years, our database has more than **5000** users, more than **2700** reports, and votes on more than **290,000** tweets.

### Selected Papers (of >10 submitted so far)

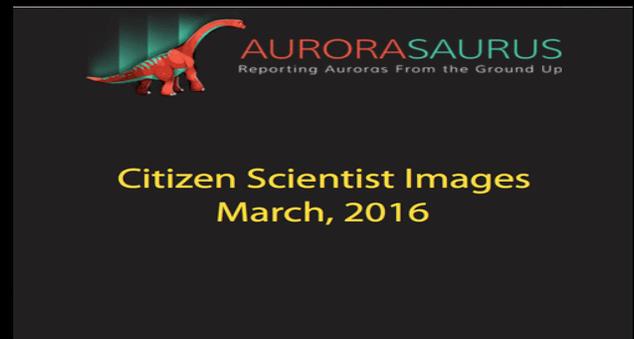
MacDonald, E. A., et al., **Aurorasaurus: A citizen science platform for viewing and reporting the aurora**, Space Weather, doi: 10.1002/2015SW001214, 2015.

Case, N. A., et al., **Mapping Auroral Activity with Twitter**, Geophys. Res. Lett., 42, doi:10.1002/2015GL063709, 2015.

Case, N. A., et al., **Aurorasaurus and the St Patrick's Day storm**, Astronomy & Geophysics, 56 (3), 2015.

Case, N. A., E. A. MacDonald, and R. Viereck (2016), **Using citizen science reports to define the equatorial extent of auroral visibility**, Space Weather, 14, doi:10.1002/2015SW001320.

Tapia, A.; Lalone, Nicolas; (2014) **Crowdsourcing Rare Events: Using Beauty to Draw Participants into Science and Early Warning Systems**, 11th International Conference on Information Systems for Crisis Response and Management (ISCRAM). May 18-21, 2014



*A new, open innovation, geospatial, crowdsourcing, open source platform and public-private partnership...*

Join us! @tweetaurora

POC: Elizabeth MacDonald, e.a.macdonald@nasa.gov



# Space science is core to our mission

- Improving research, connections to CCMC and space weather
- Connection to missions, education, and outreach



**AURORASAURUS**  
Reporting Auroras From the Ground Up



My Aurorasaurus

Logout

Did you see the aurora?

Yes

No

Verify Tweets

News

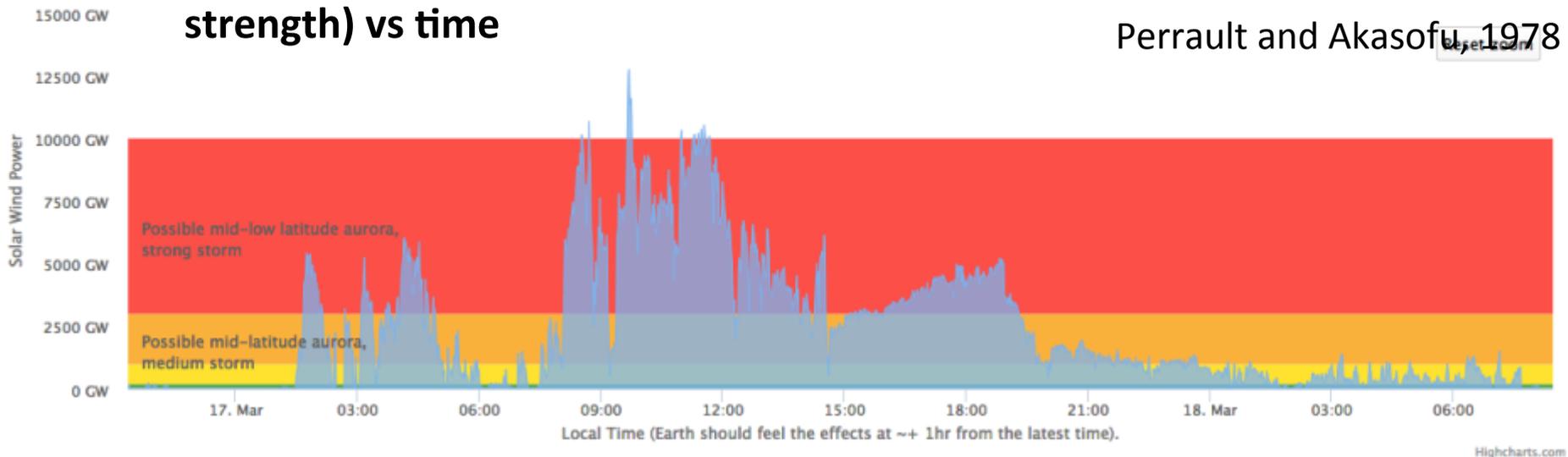
Learn

Help

## Solar wind power (related to auroral strength) vs time

$$\varepsilon = \frac{4\pi}{\mu_0} v B^2 \sin^4\left(\frac{\theta}{2}\right) l_0^2$$

Perrault and Akasofu, 1978



This graph shows the strength of solar wind power, a real-time indicator of how strong aurora will be in about one hour. The solar wind power corresponds to the energy released by the sun over time. The more energy released, the higher the power and the stronger the aurora will be.

# New global, real-time data sources from citizen scientists and tweets.



CS: Observation, Geolocation, Identification, Photography

- Hybrid approach, twitter not required. Location required, privacy protected.
- Sign up to get a free, custom aurora alert for your location.

A screenshot of the AURORASAUROS mobile application interface. The title is "Make a Report". The form includes fields for "Location" (Saskatoon, SK, Canada), "When did your observation start?" (19 Sep 2014, 1:45 PM), "When did your observation end?" (19 Sep 2014, 2:00 PM), "What colors did you see?" (Red, Green, White, Pink), "Other:" (Another color?), "What type of aurora did you see?" (Discrete Arcs, Diffuse Glow, Patches (pulsating)), "Other:" (Something different?), "Where in the sky was the aurora?" (Northern Horizon Only), "Other:" (Something different?), and "How active was the aurora?".

Carrier 1:55 PM 100%

AURORASAUROS  
Reporting Auroras From the Ground Up

Make a Report

Location:  
Saskatoon, SK, Canada

When did your observation start?  
19 Sep 2014 1:45 PM

When did your observation end?  
19 Sep 2014 2:00 PM  
 Ongoing?

What colors did you see?  
 Red  Green  White  
 Pink

Other:  
Another color?

What type of aurora did you see?  
 Discrete Arcs  Diffuse Glow  Patches (pulsating) ?

Other:  
Something different?

Where in the sky was the aurora?  
Northern Horizon Only

Other:  
Something different?

How active was the aurora?

Did you see the aurora?

Yes

No

# Inputs: Verifying tweets, a crowd-sourcing data verification activity



CS: Classification

- Registered and anonymous users verify geotagged tweets by reading the tweet and voting “yes” or “no” if they think it is a real-time sighting at correct location
  - Geotags are either embedded or extracted via CLAVIN
  - Minimal training of users
- Verified tweets used in alerts in conjunction with other observations

Sighting Details

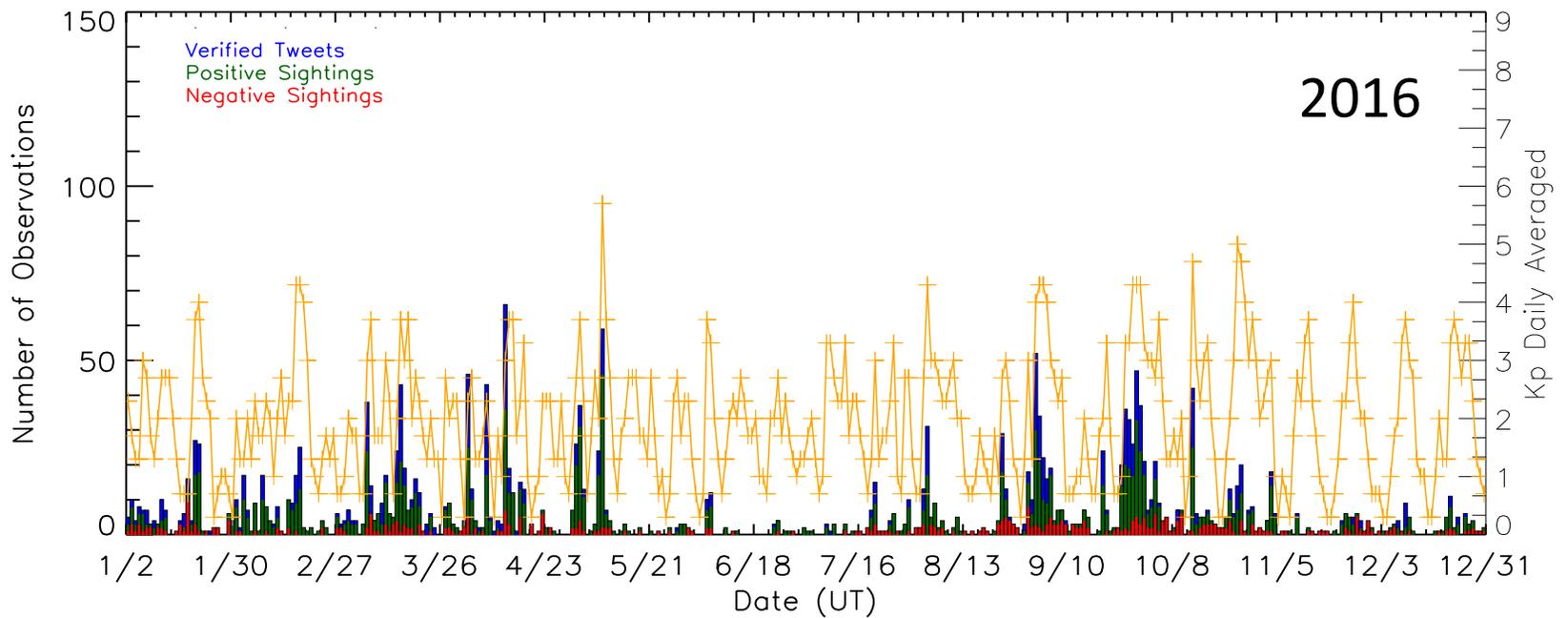
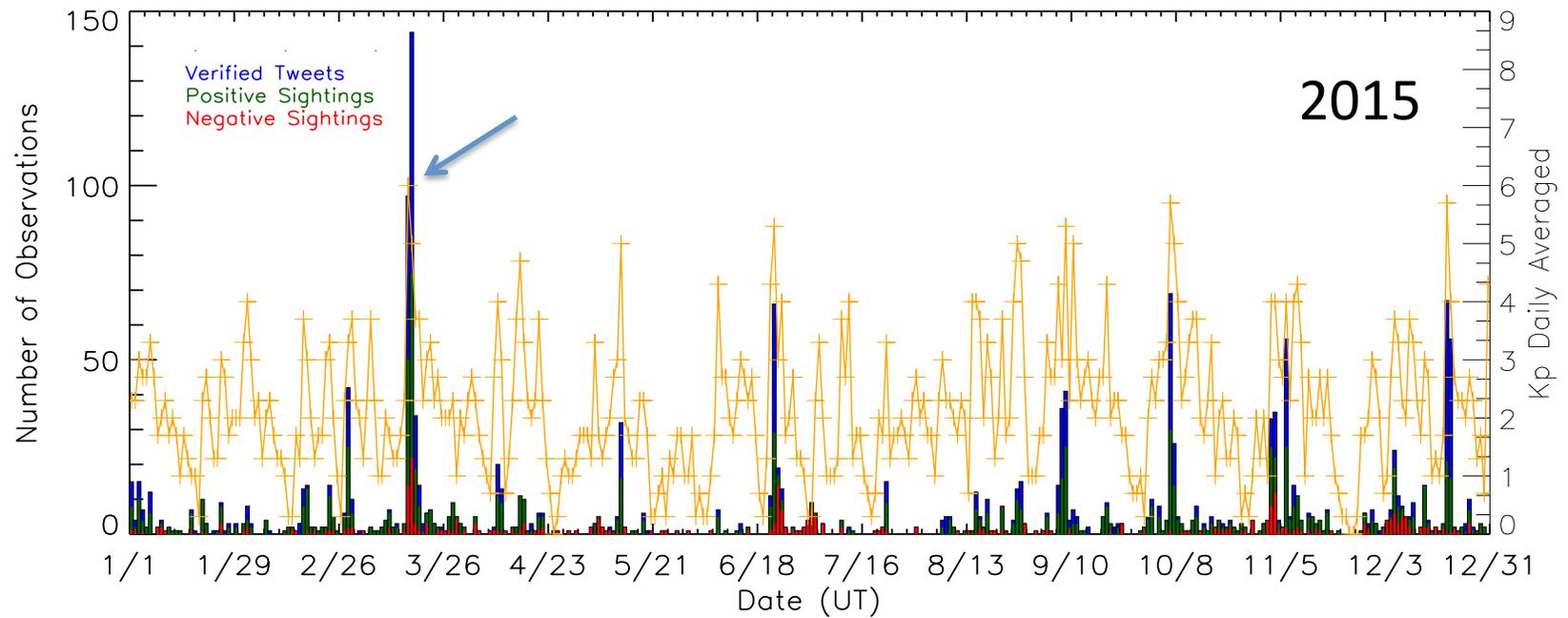
 Vonnie Valkyrie  
@ybesser24  
6/23/15 at 1:29 am

Its so beautiful in the night sky the northern lights are dancing all over!  
[#northernlights](#) [#Minnesota](#)

Did They Just See the Aurora?





# Calling Citizen Scientists Everywhere!

**Help NASA track the aurora at  
Aurorasaurus.org**

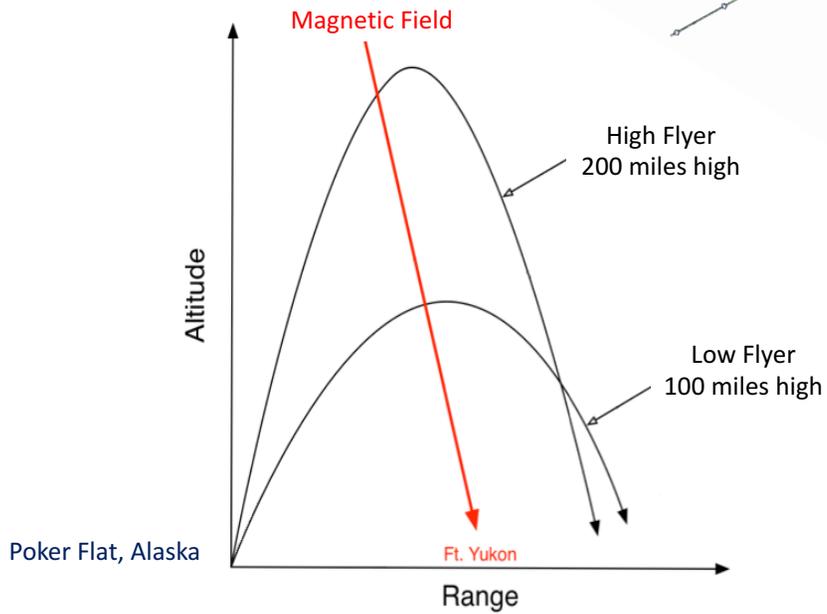
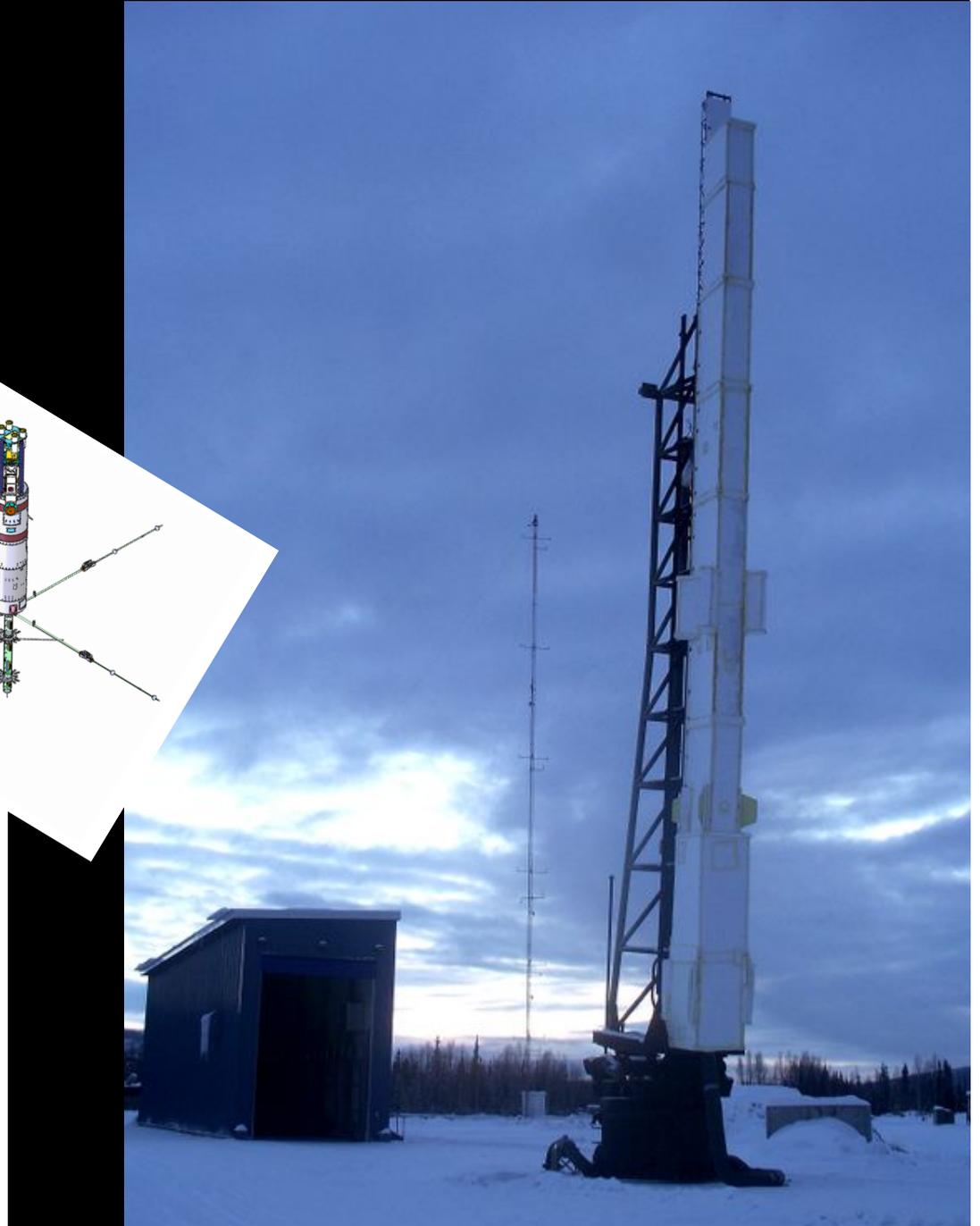
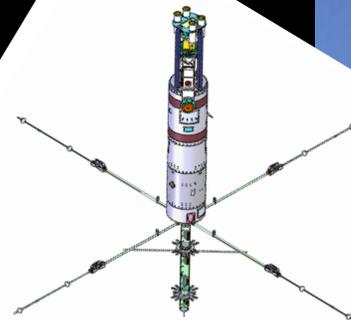
Join the conversation with  
@tweetaurora and download  
the iOS, Android apps

Partner and  
collaborate  
with us!

[aurorasaurus.info@gmail.com](mailto:aurorasaurus.info@gmail.com),  
[fb.com/aurorasaurus.org](https://www.facebook.com/aurorasaurus.org)

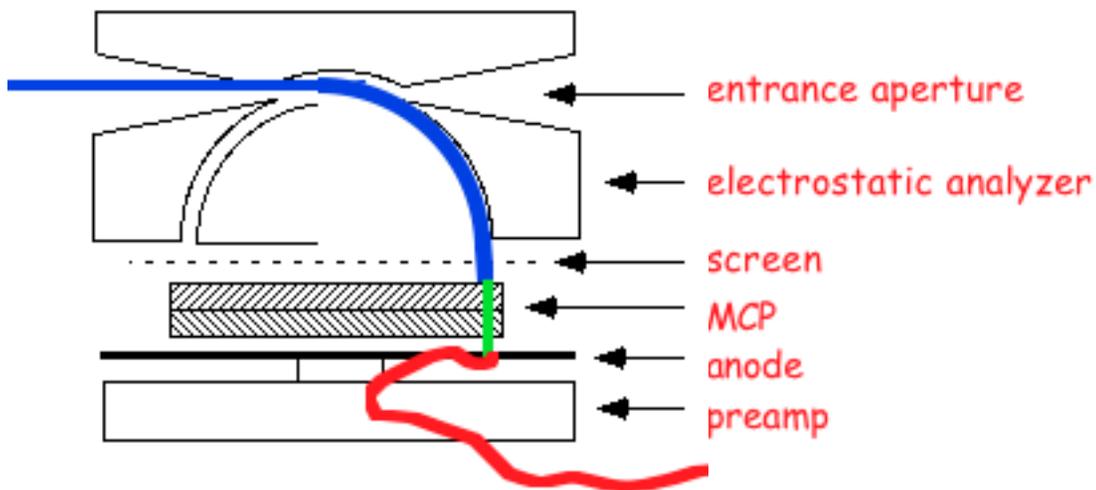


AURORASAURUS



# What experiments do we fly?

- Charged Particle Detectors
  - Electrons, ions ( $H^+$ ,  $O^+$ )
  - Electronics bend (select) particles of a certain energy and charge into the detector
  - Incoming particles must be amplified
    - 1  $e^-$  does not create enough charge to be “sensed”

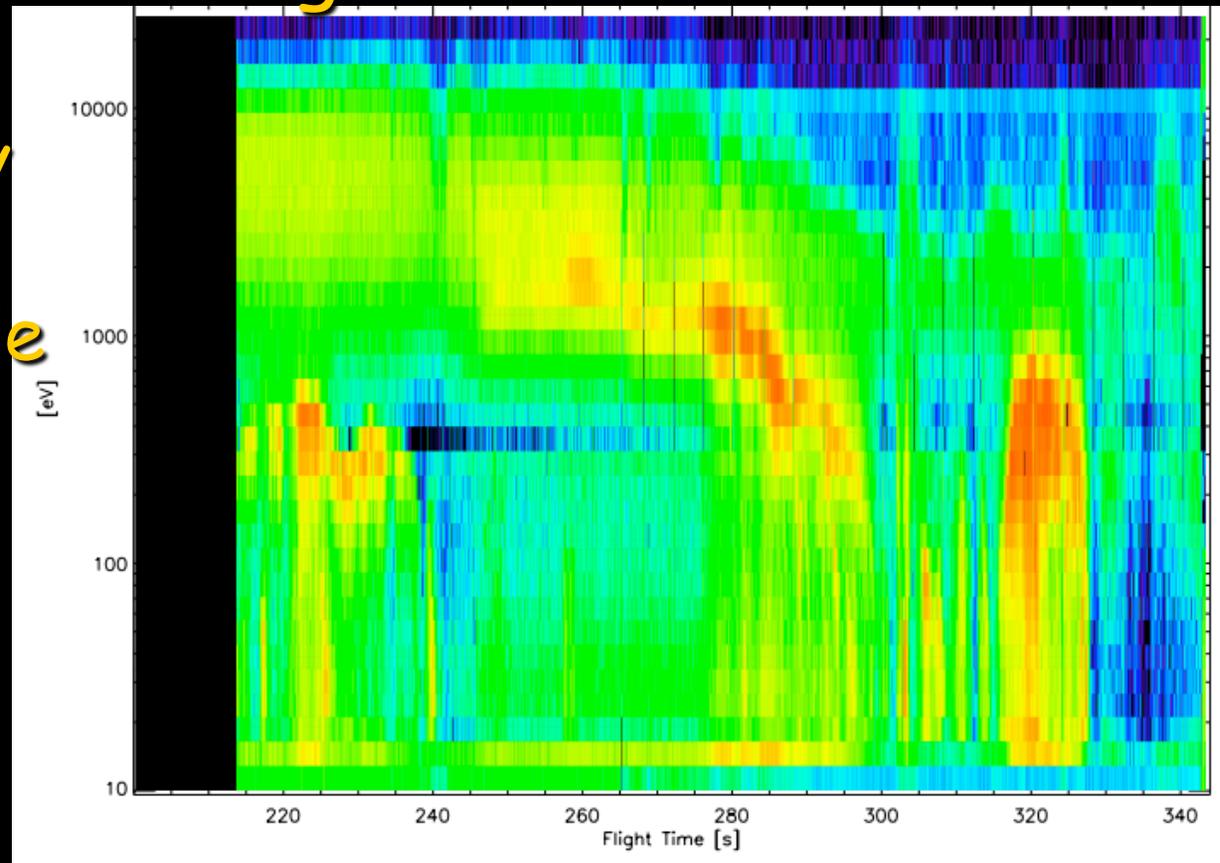


Must use “night-vision” sensors to get  $10^6$  particles out per incoming one ---> enough charge to make a detectable current

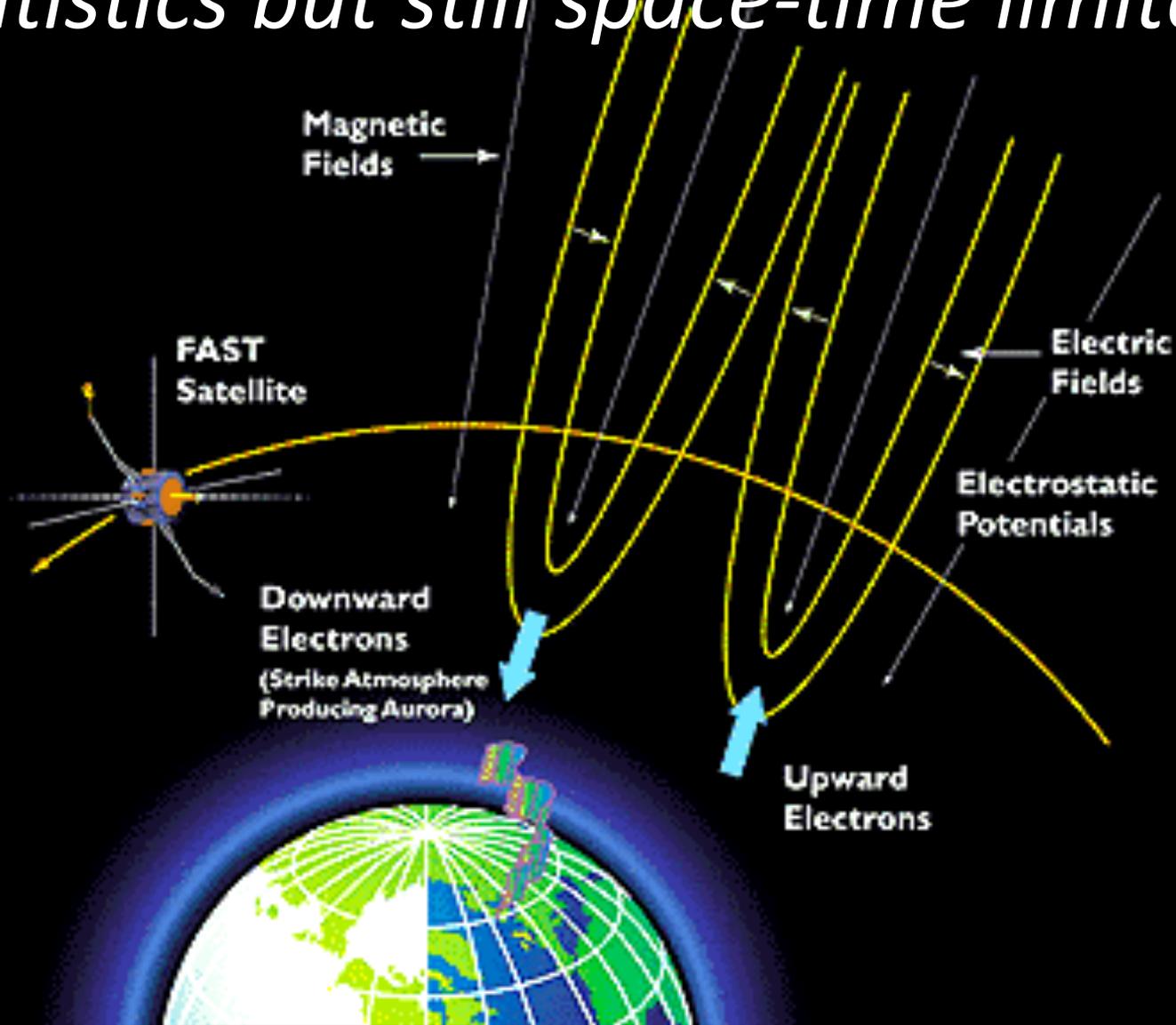
- Rocket moves through arcs, 1 pt measurement of 1 specific unique event
- Can't separate spatial boundary from change in time



- Rain analogy
- Unless you have multiple payloads

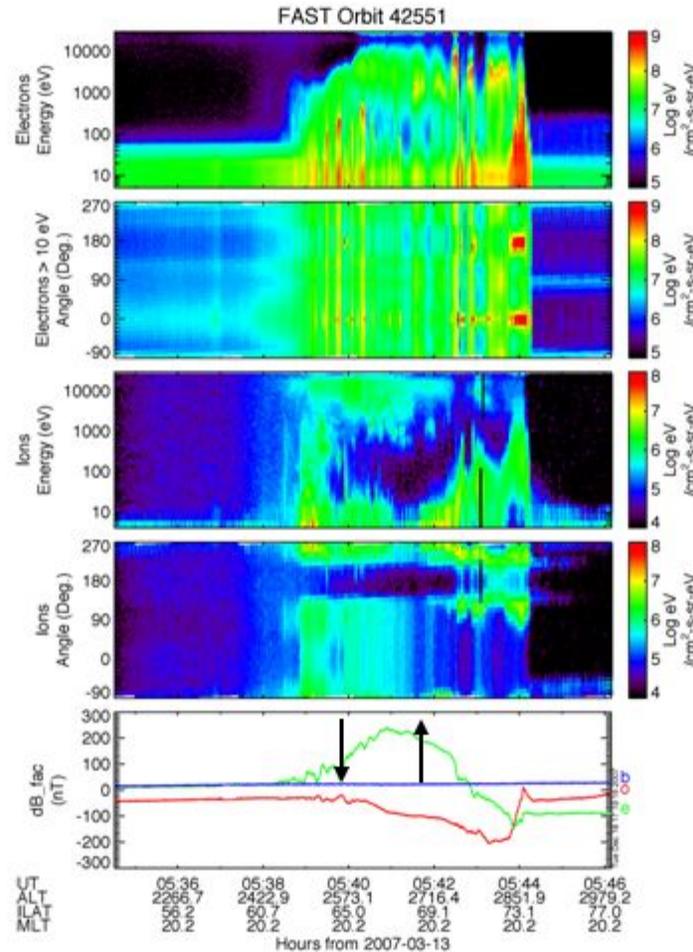


Now from satellites...  
*statistics but still space-time limited*



# Auroral Acceleration Region

Electron Energy  
 Electron Pitch Angle  
 Ion Energy  
 Ion Pitch Angle  
 Magnetic Field



Electrons carry  
 FACs

Magnetic field  
 deviations  
 correspond to  
 ionospheric flows

Arrows show FAC

# Three Regions of Auroral Acceleration

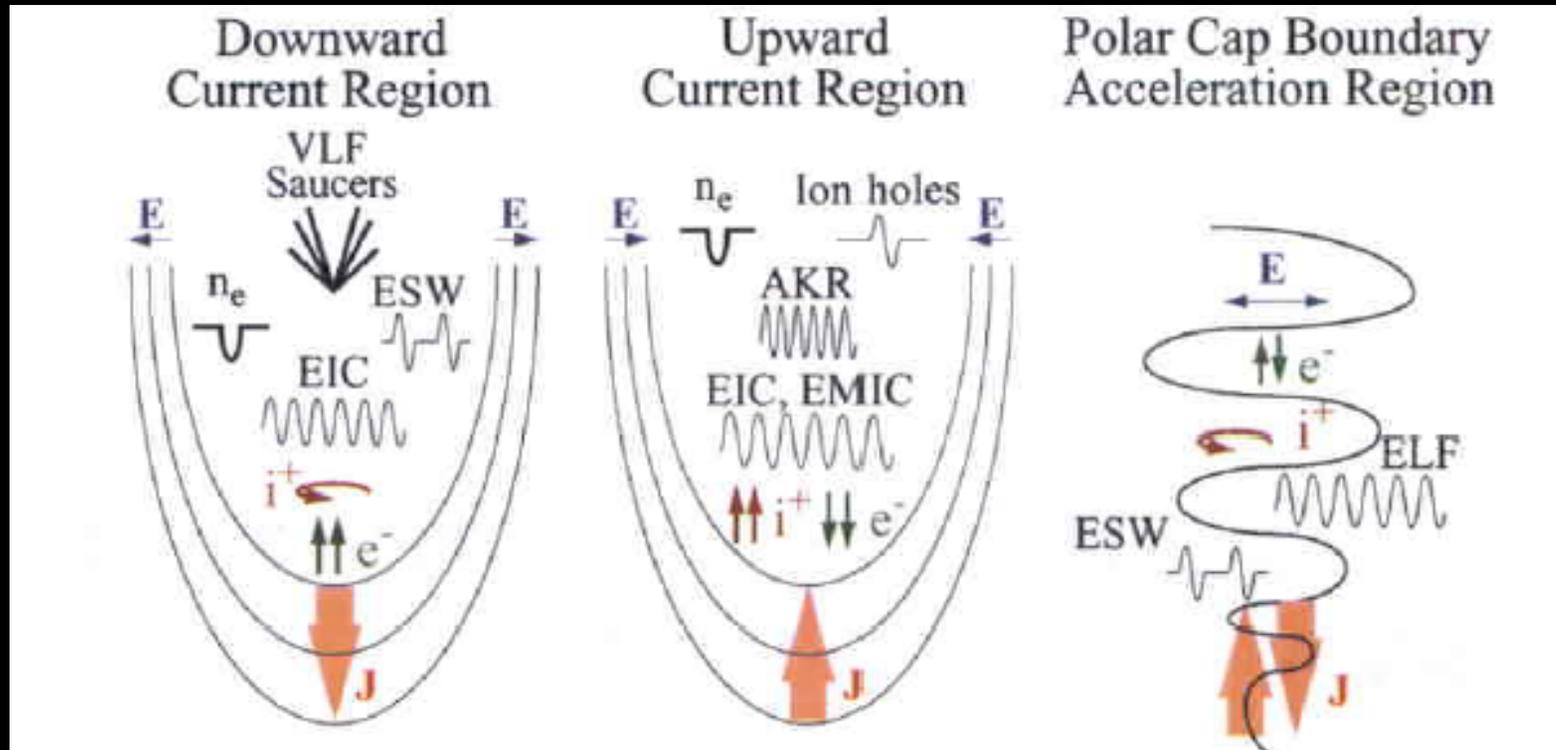


Illustration of three regions of auroral acceleration: downward current regions, upward current regions, and the region near the polar cap boundary of Alfvénic acceleration (from *Auroral Plasma Physics*, International Space Science Institute, Kluwer, 2003, adapted from Carlson et al., 1998)

Have a great summer & ask questions!

**BASIC RESEARCH IS  
WHAT I AM DOING  
WHEN I DON'T  
KNOW WHAT I AM  
DOING.**

QUOTEHD.COM

Werner von Braun

Good Goddard area restaurants: [bit.ly/LizRestaurants](http://bit.ly/LizRestaurants)

Hiking map: [bit.ly/LizHiking](http://bit.ly/LizHiking)

# The End

- Wanna help with this: Make your own aurora. DIY, and/or high tech version, <http://blog.aurorasaurus.org/?p=267>
- Upcoming launch, Sun @ 9 pm! Talk to Carina. Watch @tweetaurora @nasa\_wallops for details. You can see aurora from here and participate with Aurorasaurus.

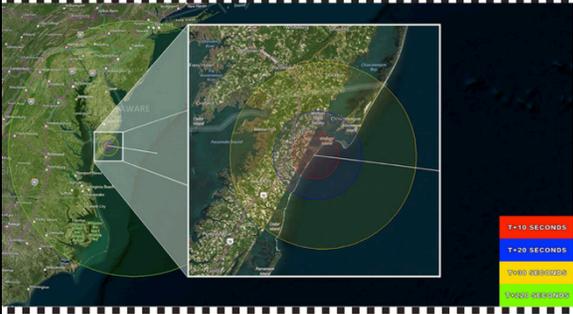


## ARTIFICIAL AURORA

NASA Sounding Rocket Launch from Wallops will release artificial clouds to better understand the ionosphere and aurora!

The rocket will be launched this Sunday, June 11th at 4:00am EST

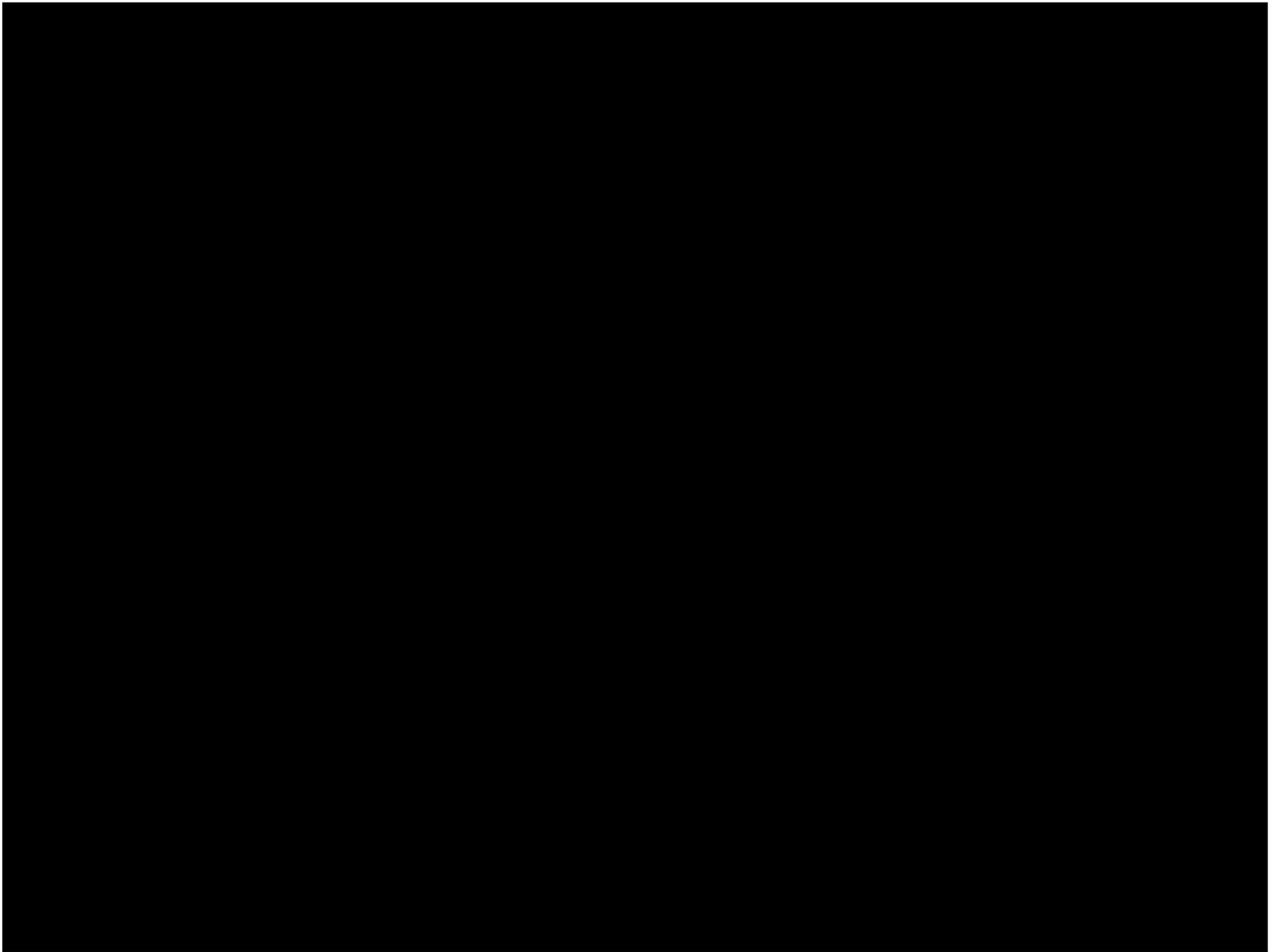
Who can see it?  
This image shows what locations are within the viewing area.



Be sure to tweet what you see with time, location, and hashtags

#AuroraLights #ArtificialAurora

[www.aurorasaurus.org](http://www.aurorasaurus.org)



# Who am I?

A word cloud on a black background featuring the following terms in various colors and orientations: Scientist (green, top left), Feminist (brown, top center), Traveller (brown, top right), Skier (brown, vertical, left of Feminist), Poet (brown, left of Feminist), Aurorasaurus.org (yellow, center), Small town girl (brown, right of Aurorasaurus.org), Hiker (brown, left of Elizabeth), Reader (brown, left of Elizabeth), Elizabeth MacDonald (large brown, center), Team leader (brown, below Elizabeth), and Creative (yellow, bottom right).

Scientist  
Feminist  
Traveller  
Skier  
Poet  
Aurorasaurus.org  
Small town girl  
Hiker  
Reader  
Elizabeth MacDonald  
Team leader  
Creative

# What I do?

A word cloud on a black background. The words are arranged in a roughly circular pattern. The largest word is 'SCIENCE' in orange. Other prominent words include 'analyze data' in yellow, 'lead teams' in green, and 'build instruments' in orange. Smaller words include 'write papers', 'understand space weather', 'social media', 'test instruments', 'build website', 'outreach', and 'understand spacecraft charging'.

understand space weather write papers  
analyze data  
social media lead teams  
test instruments build website outreach  
SCIENCE  
build instruments  
understand spacecraft charging

facebook.com/aurorasaurus.org

Create

macdonald@lanl.gov

Inquire <http://vanallenprobes.jhuapl.edu/>

THINK

Explore

spaceweather.com

Educational

Aurorasaurus.org  
@spaceyliz

Beautiful

Question

Fun

Inspirational  
Persist

Wordle.net

Interesting

